Earth Science and Applications from Space

National Imperatives for the Next Decade and Beyond

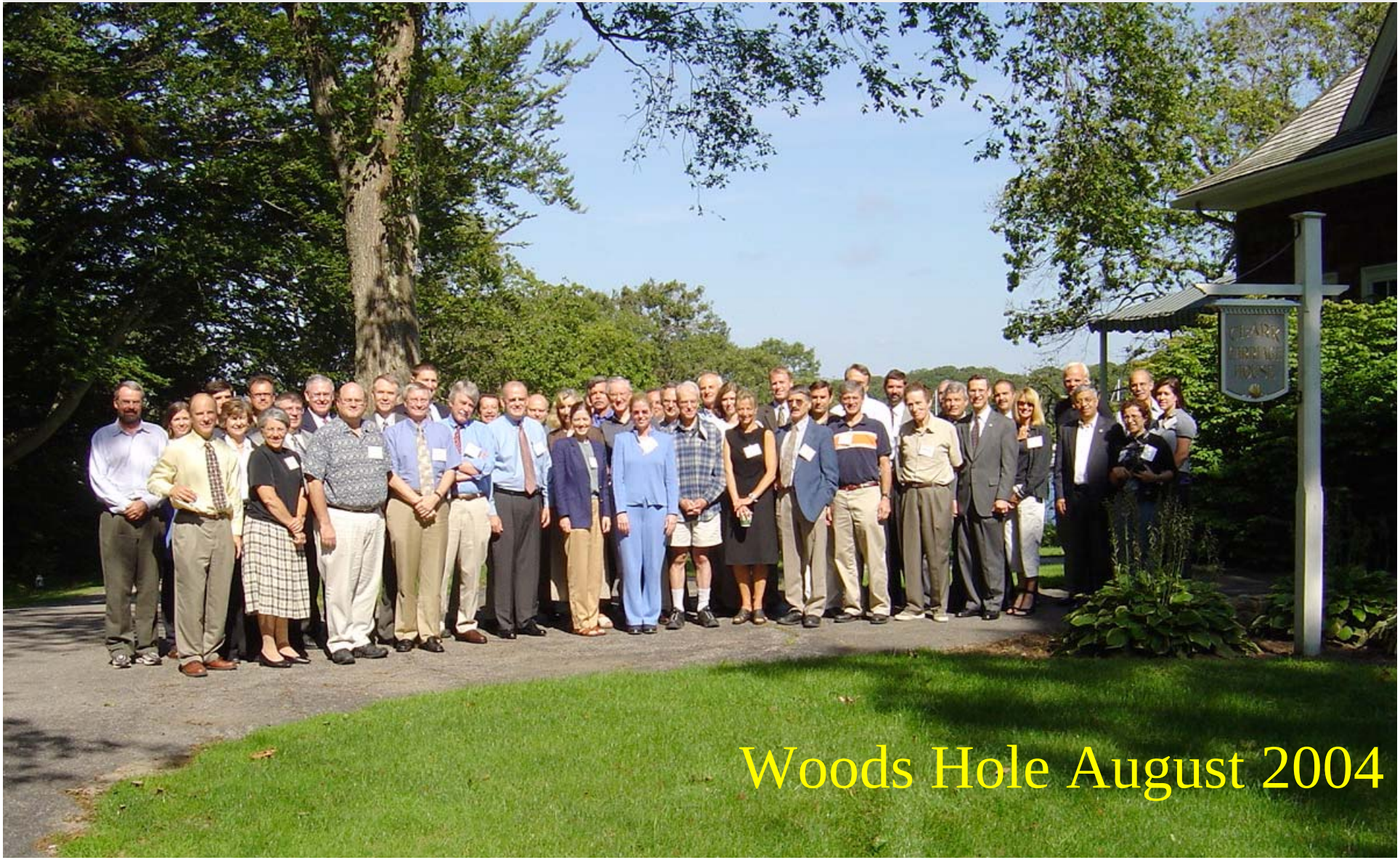
Rick Anthes

March 7, 2007

Irvine-Water Cycle Workshop

Prepublication: http://www.nap.edu/catalog/11820.html

Long ago and far away....



ESAS Charge

- Recommend a prioritized list of flight missions and supporting activities to support national needs for research and monitoring of the dynamic Earth system during the next decade.

- Identify important directions that should influence planning for the decade beyond.

Sponsors: NASA SMD, NOAA NESDIS, USGS Geography

CHALLENGES

- Community Buy-in
  - First decadal survey
  - Breadth of interests
    - An organizational challenge was how to cover science/application themes as well as scientific disciplines. in retrospect, having additional discipline-focused subgroups would have been useful
- Multi-Agency Issues
  - Transition to Operations
  - Sustained Research Operations
- Important changes during the study at NASA and NOAA
  - Budgets
  - NPOESS
  - GOES

The Alamo

But the Community did it!

Executive Committee

1. Rick Anthes, UCAR, co-chair, atmospheric science
2. Berrien Moore, U. New Hampshire, co-chair, biogeochemical cycling
3. Jim Anderson, Harvard, atmospheric science, chemistry
4. Bruce Marcus, TRW (ret), remote sensing
5. Bill Gail, Ball Microsoft Virtual Earth, civil space and IT
6. Susan Cutter, U. South Carolina, hazards and risk
7. Tony Hollingsworth, ECMWF, weather forecasting
8. Kathie Kelly, U. Washington, physical oceanography/satellite obs
9. Neal Lane, Rice, policy
10. Warren Washington, NCAR, climate
11. Mary Lou Zoback, RMS, solid earth

Panel Chairs

12. Tony Janetos, PNL/U. Md., ecology and land remote sensing
13. Brad Hagar, MIT, solid earth
14. Ruth DeFries, U. Maryland, land cover change and remote sensing
15. Susan Avery, CIRES and CU, meteorology, space weather
16. Eric Barron, U. Texas, climate, paleoclimate
17. Dennis Lettenmaier, U. Washington, hydrology
18. Mark Wilson, U. Michigan, infectious disease and remote sensing

Water Panel members

- Dennis Lettenmaier (University of Washington, chair)
- Anne Nolin (Oregon State University, co-chair)
- Wilf Brutsaert (Cornell University)
- Anny Cazenave (LEGOS-CNES, Toulouse)
- Carol Anne Clayson (Florida State University)
- Jeff Dozier (University of California, Santa Barbara)
- Dara Entekhabi (Massachusetts Institute of Technology)
- Rick Forster (University of Utah)
- Charles Howard (independent consultant)
- Chris Kummerow (Colorado State University)
- Steve Running (University of Montana)
- Charles Vorosmarty (University of New Hampshire)

Water Panel top 7 missions

1) Soil Moisture

2) Surface water/coastal oceanography (swath altimetry+)
3) Cold land processes

4) Groundwater/ocean mass (GRACE+)
5) Water vapor transport (WOWS/AIRS+)
6) Glacier mass balance/sea ice thickness
7) Inland water quality

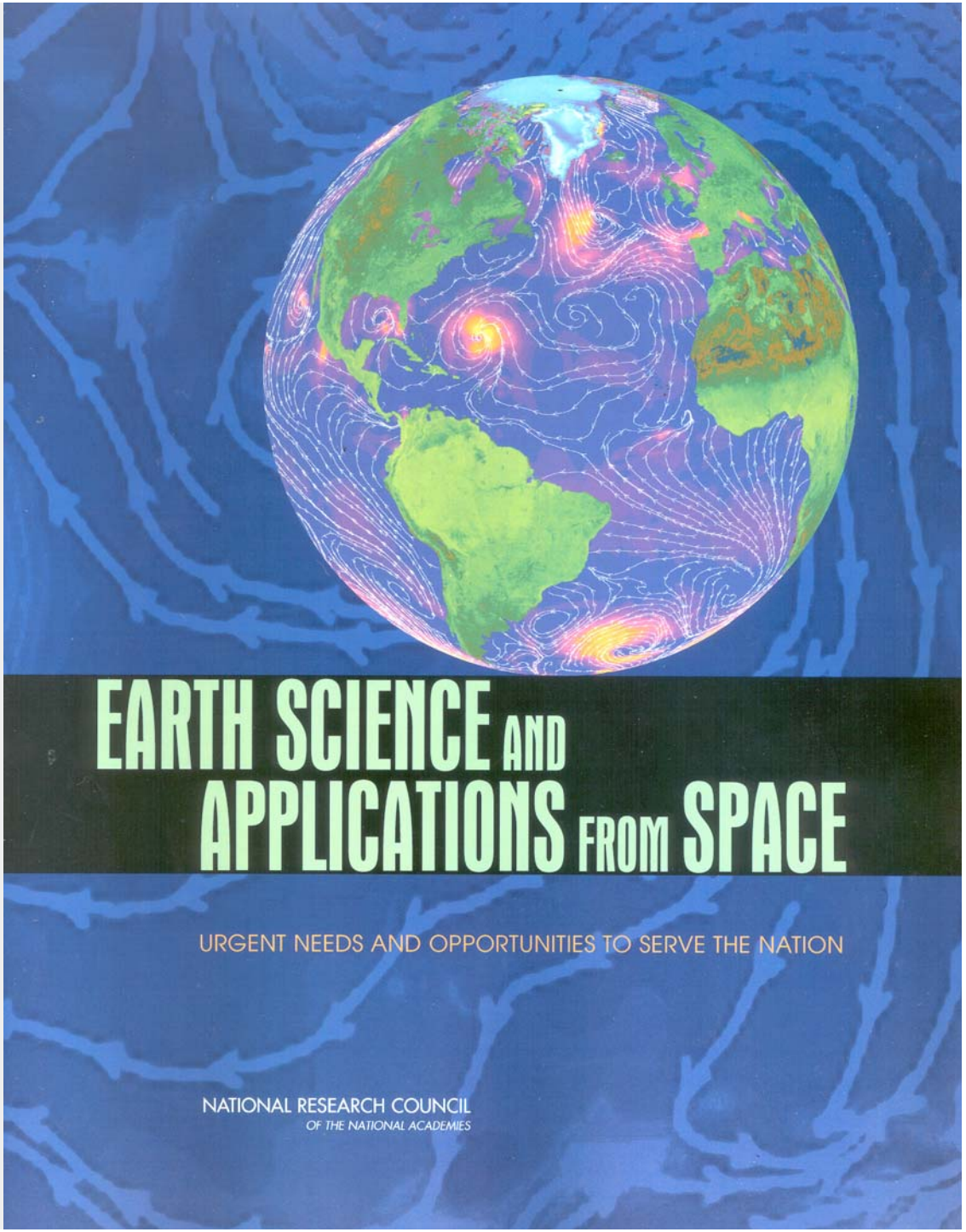
VISION

A healthy, secure, prosperous

and sustainable society for

all people on Earth

> ***"Understanding the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most important for society as it seeks to achieve prosperity and sustainability."***
>
> ***NRC (April 2005)***



Interim Report 2005

"Today, this system of environmental satellites is at risk of collapse."

Interim Report

- Overriding Concern: Absence of Plans for Future Research Missions (Mission Queue)
- Consequences of canceled, descoped, and delayed missions: LDCM, OVWM, GIFTS, Glory (APS and TIM), WSOA, and GPM
- Delays in Explorer (Earth System Science Pathfinder) line
- Steps to ensure climate data records
- Technology base to support new missions, for example:
  - InSAR
  - Wide-swath ocean altimetry
  - Measurement from space of tropospheric winds

Recommendations related to above

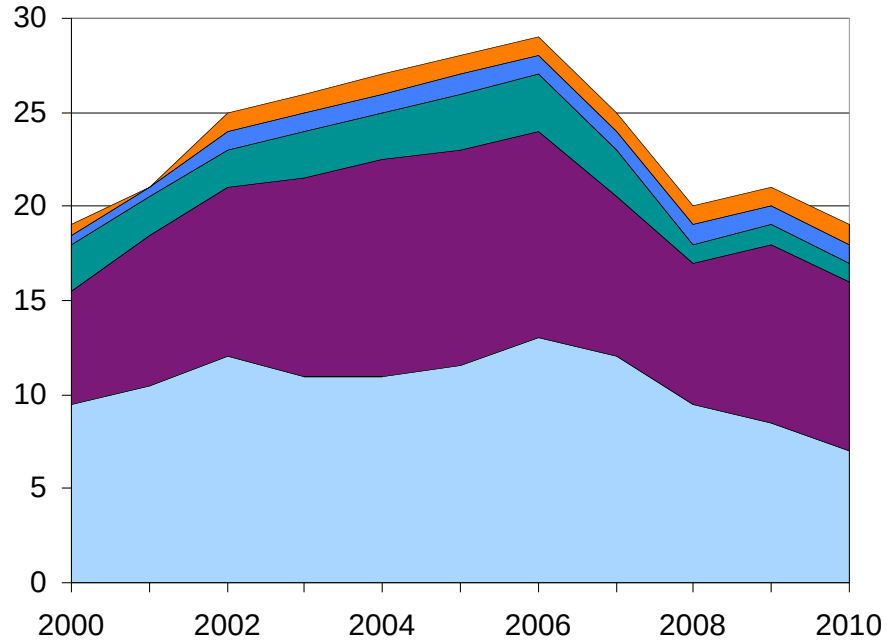
Since the Interim Report

Since the Interim Report…

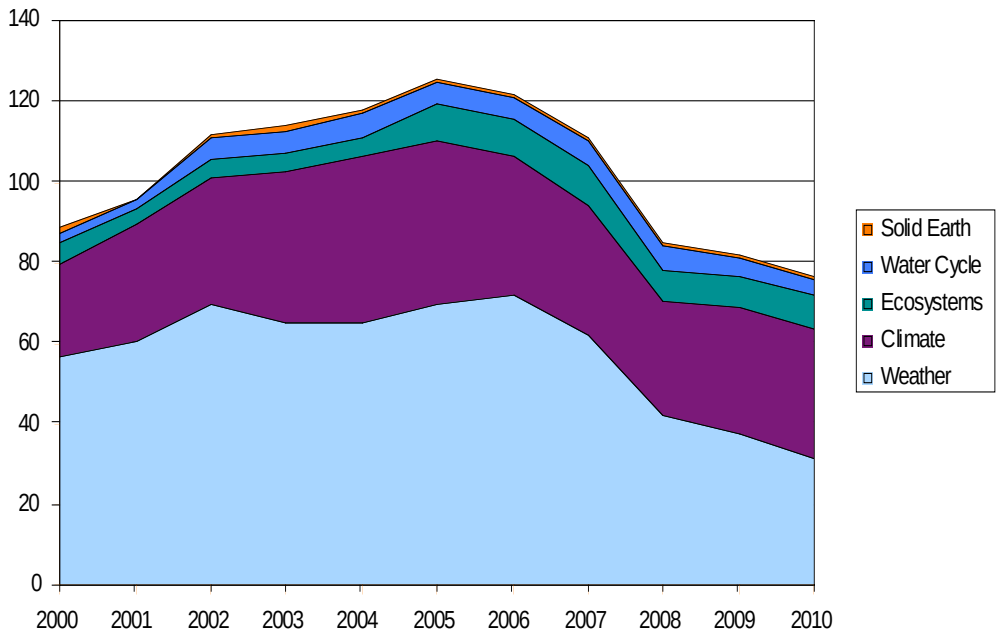
- **NPOESS**
  - Multibillion dollar overuns, launch C1 slips to 2013, reduction of number of spacecraft from 6 to 4 and loss of mid-morning orbit
  - CMIS: off of C-1 and Descoped Version Thereafter--? Vector Winds, ? SST
  - Climate-related measurements now "secondary" – gone unless new $
    1. Total Solar Irradiance Sensor (TSIS)
    2. Earth Radiation Budget Sensor (ERBS)
    3. Ocean Altimeter (ALT)
    4. Ozone Mapping and Profiler Suite (OMPS Limb)
    5. Aerosol Polarimeter Sensor (APS)
  - Space environment sensors descoped
  - Operational land remote sensing (OLI) option off the table

- **NASA Terminates Two More Missions and Delays Two Others**
  - DSCOVR (Deep Space Climate Observatory, fmr Triana)
  - HYDROS
  - GPM Delayed 2.5 years (and in August '06, signs that mission will be delayed further, or zeroed)
  - NPP Delayed another 1.5 years
  - R&A cuts 15^{+} %

Trends In Earth Observations Missions From Space

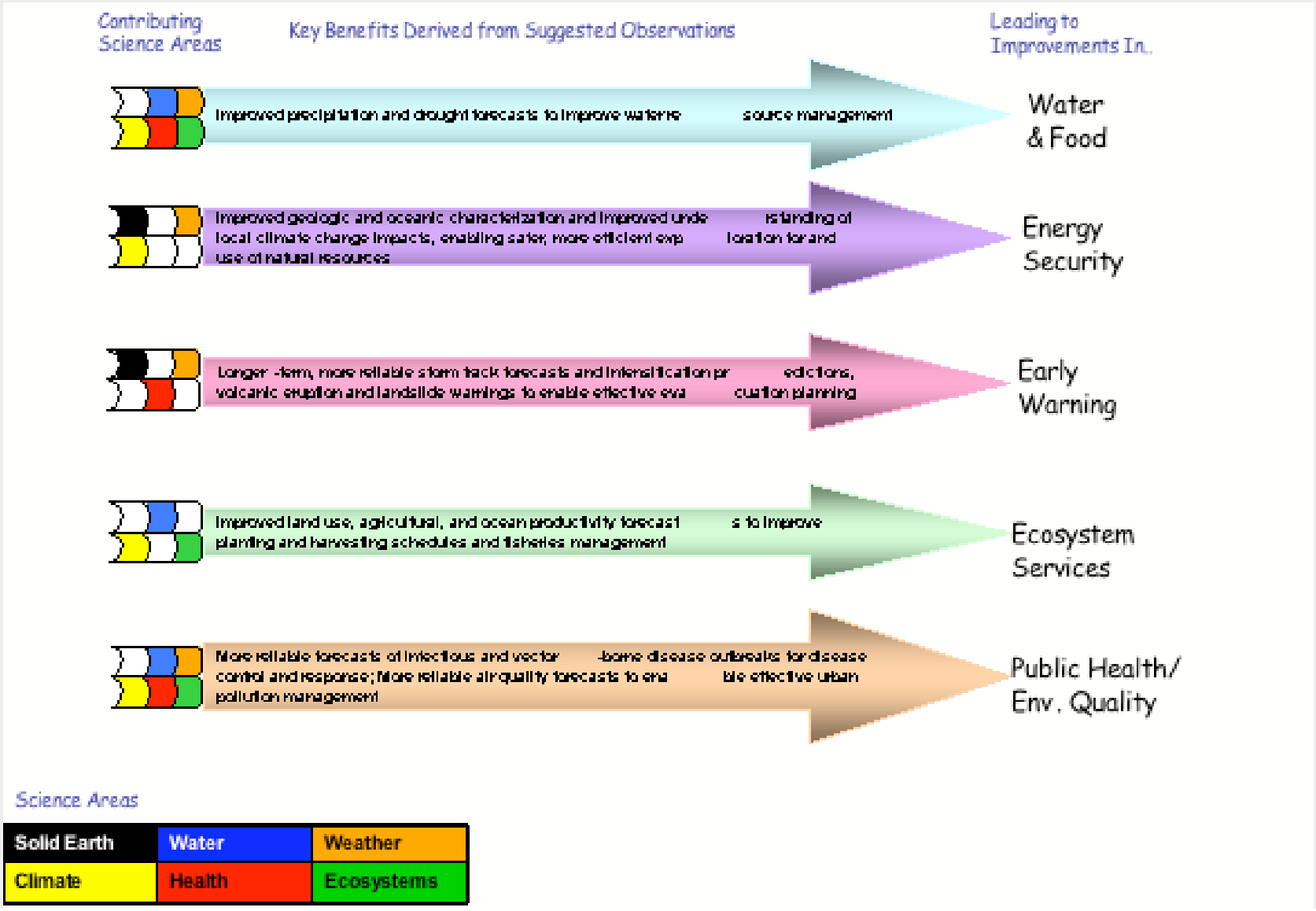


Number of Missions



Number of Instruments

Need for Interdisciplinary Program



FINAL REPORT

- Recommends a Path Forward that Restores US Leadership in Earth Science and Applications and averts the Potential Collapse of the System of Environmental Satellites
- Presents an Integrated Suite of Missions
  - Panel recommendations rolled-up
  - Missions sequenced
  - Overall cost matched to anticipated resources plus reasonable growth
- Highest Priorities of Each Panel Preserved
- Some Guidance on How To Handle Budget or Technology Development Problems

OVERARCHING RECOMMENDATION

- The U.S. government, working in concert with the private sector, academe, the public, and its international partners, should renew its investment in Earth observing systems and restore its leadership in Earth science and applications.

KEY AGENCY RECOMMENDATIONS
(for currently planned observing system)

- NOAA-restore key climate, environmental, and weather capabilities to NPOESS mission
  - Total solar irradiation and Earth radiation
  - Passive ocean surface vector winds and sea-surface temperatures
  - Ozone Monitoring and Profiling Suite (OMPS)

KEY AGENCY RECOMMENDATIONS
(for currently planned observing system)

- **NOAA-restore capability to make high-temporal and vertical-resolution measurements of temperature and water vapor on GOES-R**
  - **Complete GIFTS, orbit via launch of opportunity and/or**
  - **Extend the HES Study focusing on cost-effective approaches to achieving essential sounding capabilities in the GOES-R time frame.**

KEY AGENCY RECOMMENDATIONS

(for currently planned observing system)

- **NASA-continuity of precipitation and land cover**
  - **Launching GPM by 2012**
  - **Obtaining a replacement to Landsat 7 data before 2012.**
- **The committee also recommends that NASA continue to seek cost-effective, innovative means for obtaining land cover change information.**

MAIN RECOMMENDATION
(for next decade)

- NOAA and NASA should undertake a set of 17 recommended missions, phased over the next decade

MAIN RECOMMENDATION
(for next decade)

- NOAA research to operations
  - Vector ocean winds
  - GPS radio occultation temperature, water vapor and electron density profiles
  - Total solar irradiance/and Earth Radiation (NPP) and restored to NPOESS
- NASA
  - 15 missions in small, medium and large categories

17 Missions

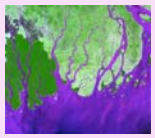
(Red = <$900 M; Green = $300-$600 M; Blue = <$300 M)

Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 - 2013—Missions listed by cost				
CLARREO (NOAA portion)	Solar and Earth radiation characteristics for understanding climate forcing	LEO, SSO	Broadband radiometer	$65 M
GPSRO	High accuracy, all-weather temperature, water vapor, and electron density profiles for weather, climate, and space weather	LEO	GPS receiver	$150 M
Timeframe 2013 – 2016				
XOVWM	Sea surface wind vectors for weather and ocean ecosystems	MEO, SSO	Backscatter radar	$350 M

Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	$300 M
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	$300 M
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter	$700 M
Timeframe: 2013 – 2016, Missions listed by cost				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	$300 M
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser	$400 M
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar	$450 M
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers	$550 M
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar	$800 M

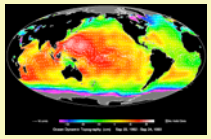
Timeframe: 2016 -2020, Missions listed by cost				
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter	$300 M
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST[a]	GEO	MW array spectrometer	$450 M
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system	$450 M
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers	$500 M
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	$600 M
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	$650 M

[1] Cloud-independent, high temporal resolution, lower accuracy SST to complement, not replace, global operational high-accuracy SST measurement



River discharge estimates

SWOT
Launch 2013-2016

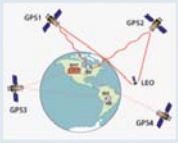


Changes in aquifers and deep ocean currents

GRACE-II
Launch 2016-2020

Snow pack accumulation and Snowmelt extent

Snow water equivalent, snow depth, and snow wetness

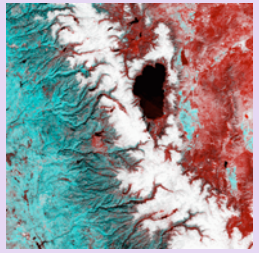


Pressure/ temperature/ water vapor profiles

GPSRO
Launch 2010-2013

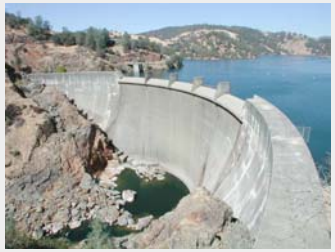
Temperature and humidity profiles

PATH
Launch 2016-2020



Dynamics of water storage in seasonal snow packs

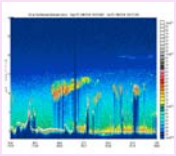
SCLP
Launch 2016-2020



Societal Challenge: **Freshwater Availability**
Improved precipitation and drought forecasts to improve water resource management

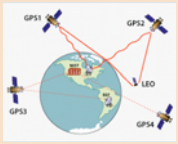
Linkage between terrestrial water, energy, and carbon cycle

SMAP
Launch 2010-2013



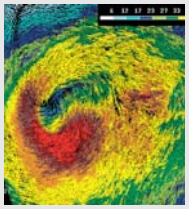
Cloud and aerosol height

ACE
Launch 2013-2016



Pressure/ temperature/ water vapor profiles

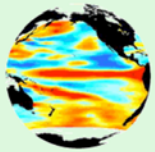
GPSRO
Launch 2010-2013



High resolution ocean vector winds

XOVWM
Launch 2013-2016

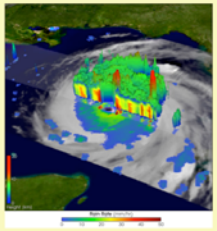
Temperature and humidity profiles



Sea surface temperature

PATH
Launch 2016-2020

Three dimensional tropospheric wind profiles

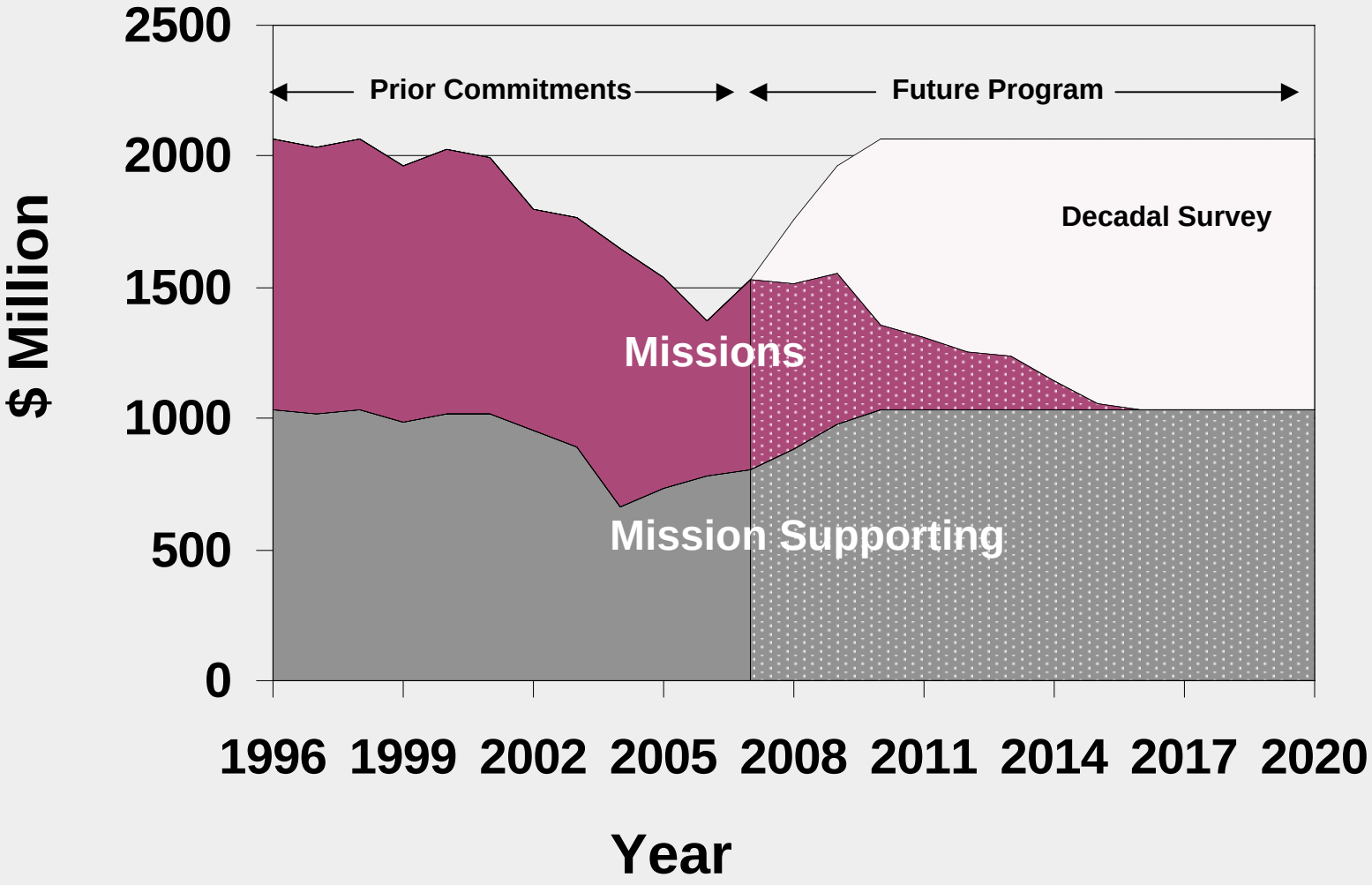


Hurricane wind fields

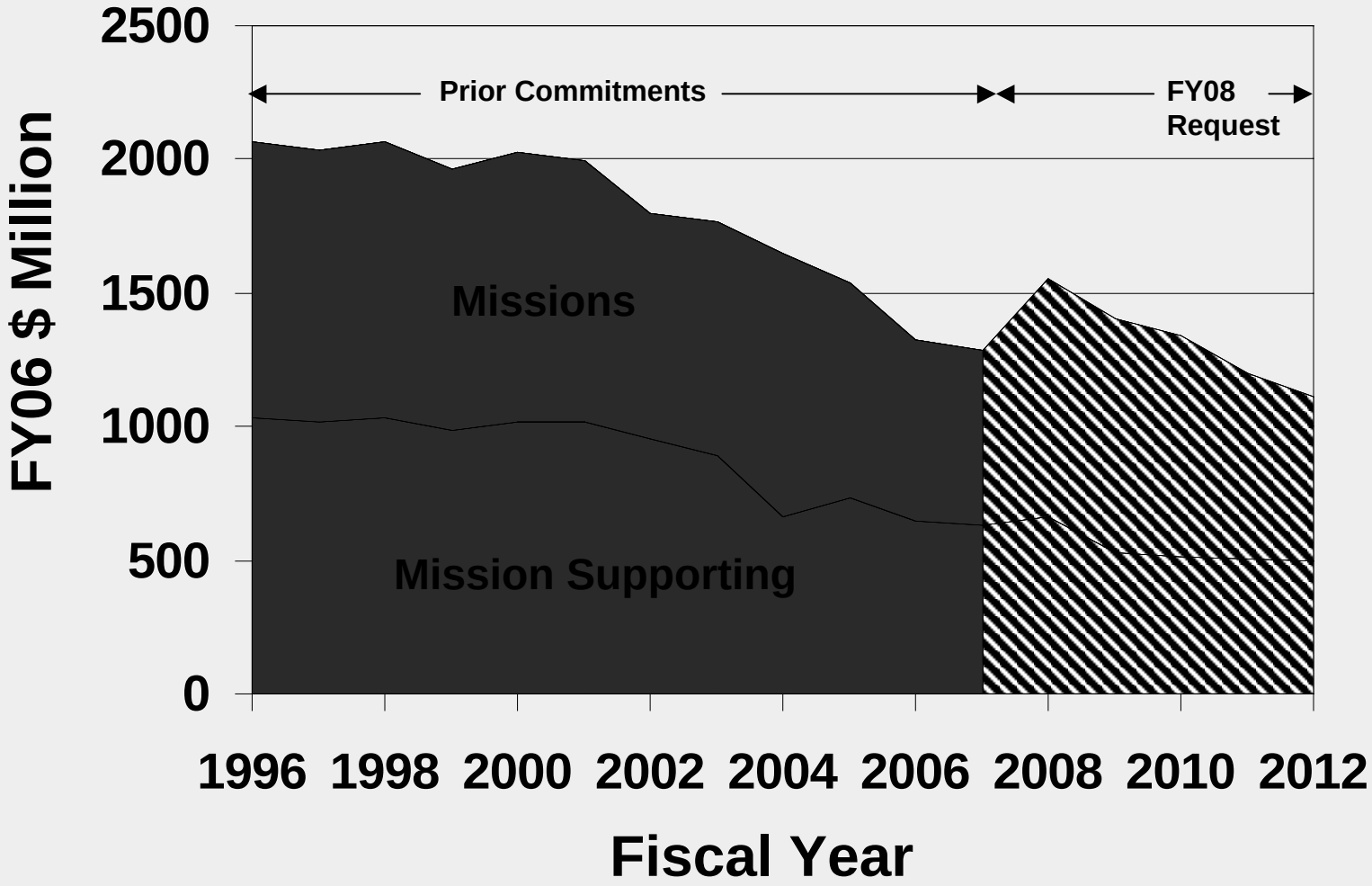
3D-Winds
Launch 2020+

Societal Challenge: **Improved Weather Prediction**
Longer-term, more reliable weather forecasts

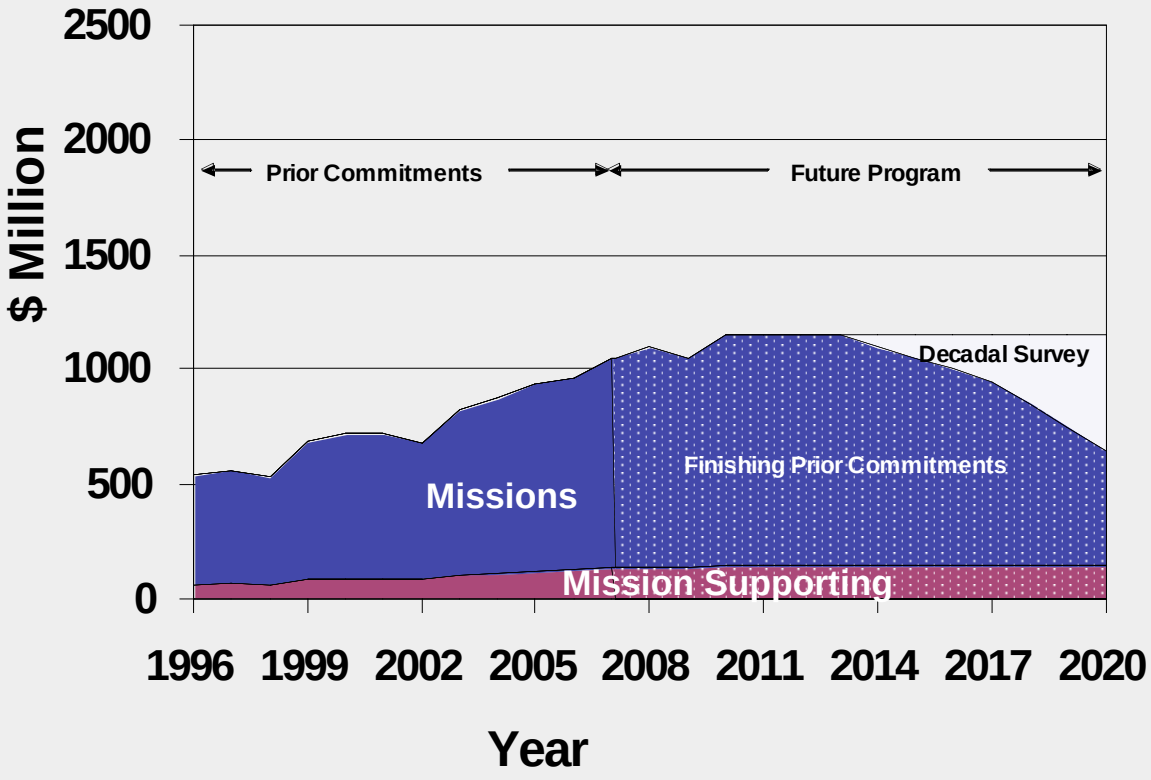
NASA Earth Science Program: Rapid Return to 2000 Funding Levels



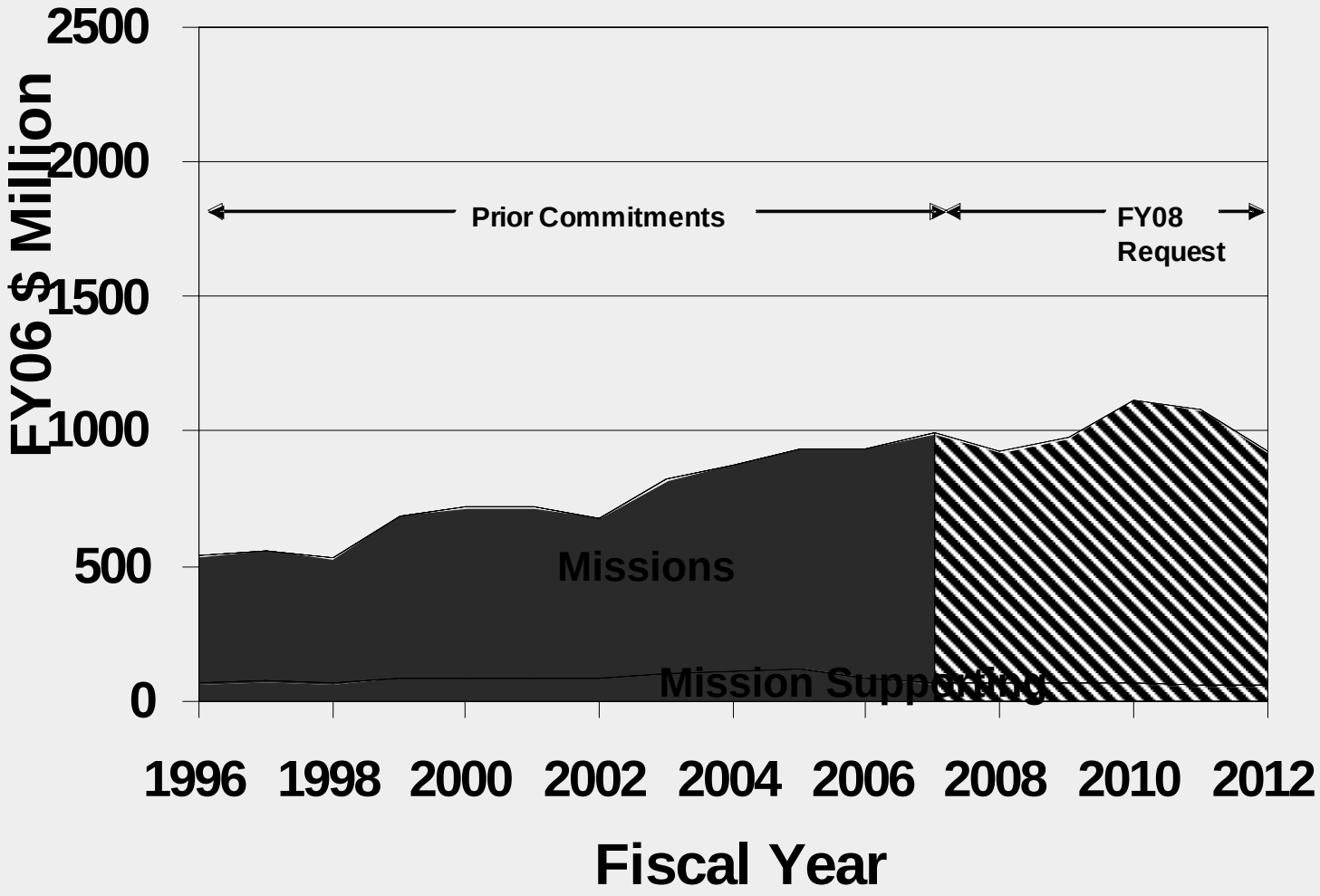
NASA Earth Science Program: A Substantial Funding Decline



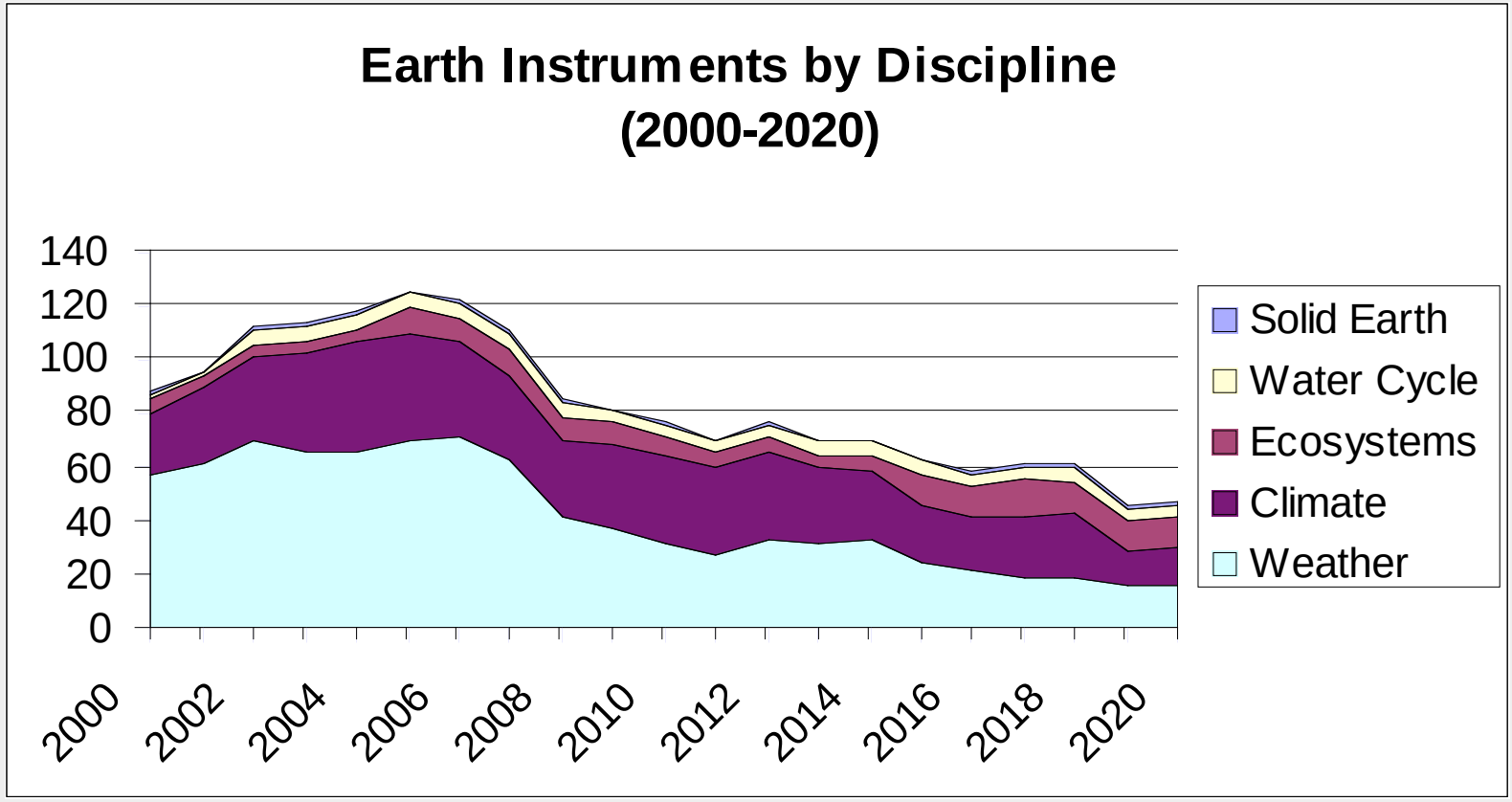
Implementing the Decadal Survey (NOAA Budget)



FY08 NOAA Budget Request



The decadal plan provides a minimal, yet robust observational system



Reaction

"At a time when accurate weather forecasting and climate research is becoming increasingly important to the well-being of our citizens, this distinguished panel of experts is warning in no uncertain terms that 'the United States' extraordinary foundation of global observations is at great risk.'"

- House Science and Technology Committee Chairman Gordon

Reaction

"You don't have to be a space or climate expert to recognize that this country's ability to track climate and environmental changes from space is heading in the wrong direction. At a time when concerns about global warming are rising, the Bush administration is sharply reducing the number of satellites that can measure the impact of rising temperatures and a host of other environmental trends."

- New York Times, Editorial, January 21, 2007

We made a Washington Post Cartoon!

Earth Science and Applications from Space:
National Imperatives for the Next Decade and Beyond

Prepublication version available now at

http://www.nap.edu/catalog/11820.html

Backup Slides

Organization of Study

- Executive Committee (18 members)
- Seven Thematically-Organized Panels
  1. Earth Science Applications and Societal Needs
  2. Land-use Change, Ecosystem Dynamics and Biodiversity
  3. Weather (incl. space weather and chemical weather)
  4. Climate Variability and Change
  5. Water Resources and the Global Hydrologic Cycle
  6. Human Health and Security
  7. Solid-Earth Hazards, Resources and Dynamics

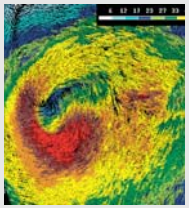
Charge to Panels

1. Identify needs and opportunities for observations from space to advance Earth science and applications for the next decade and beyond;
2. Propose programs or missions to meet these needs and opportunities, in priority order;
3. Describe each proposed mission in terms of
   - Contributions to science and applications
   - How it meets prioritization criteria
   - Benefits to society
   - Technical aspects
   - Schedule
   - Costs
4. Briefly identify needs for obs that are needed to complement space-based obs
5. Identify essential other components (telemetry, data processing, management and stewardship)

Criteria for Prioritization

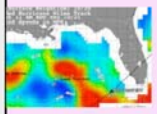
- Contributes to the most important scientific questions facing Earth sciences today (scientific merit-discovery, exploration);
- Contributes to applications and policy making (societal benefits);
- Contributes to long-term observational record of the Earth;
- Complements other observational systems, including national and international plans;
- Affordable (cost considerations, either total costs for mission or costs per year);
- Degree of readiness (technical, resources, people);
- Risk mitigation and strategic redundancy (backup of other critical systems);
- Makes a significant contribution to more than one thematic application or scientific discipline.

Above not in priority order



High resolution ocean vector winds

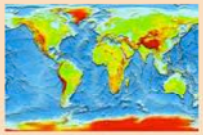
XOVWM
Launch 2013-2016



Sea level measurements extended into coastal zones

Ocean eddies and currents

SWOT
Launch 2013-2016



Global high resolution topography

Detection of active faults

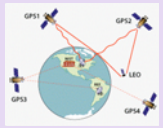
LIST
Launch 2016-2020

Snow pack accumulation and Snowmelt extent

SCLP
Launch 2016-2020

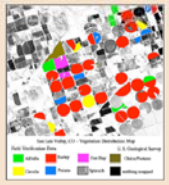
Changes in Earth's surface and movement of magma

DESDynI
Launch 2010-2013



Pressure/ temperature/ water vapor profiles

GPSRO
Launch 2010-2013

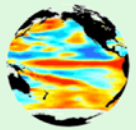


Nutrients and water status of vegetation, soil type and health

Processes indicating volcanic eruption

HysplRI
Launch 2013-2016

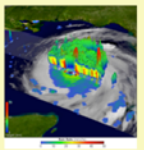
Temperature and humidity profiles



Sea surface temperature

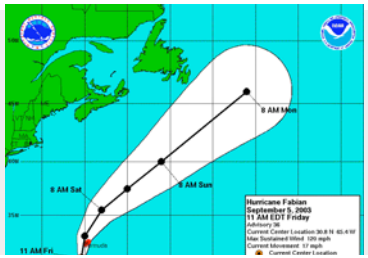
PATH
Launch 2016-2020

Three dimensional tropospheric wind profiles



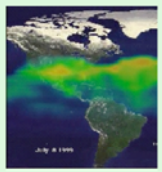
Hurricane wind fields

3D-Winds
Launch 2020+



***Societal Challenge:* Extreme Event Warnings**

Longer-term, more reliable storm track forecasts and intensification predictions, volcanic eruption and landslide warnings to enable effective evacuation planning.



Identification of human vs. natural sources for aerosols and ozone precursors

Observation of air pollution transport in North, Central, and South America

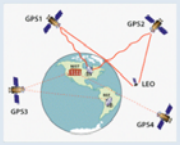
GEO-CAPE
Launch 2013-2016

Temperature and humidity profiles

PATH
Launch 2016-2020

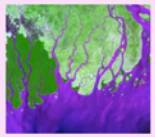
Three dimensional tropospheric wind profiles

3D-Winds
Launch 2020+



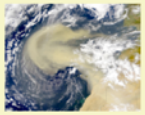
Pressure/ temperature/ water vapor profiles

GPSRO
Launch 2010-2013



River discharge estimates

SWOT
Launch 2013-2016



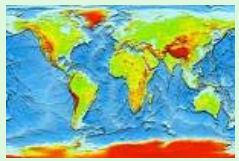
Global aerosol and air pollution transportation and processes

GACM
Launch 2016-2020

Societal Challenge: **Human Health**
More reliable forecasts of infectious and vector-borne disease outbreaks for disease control and response

Changes in Earth's surface

DESDynI
Launch 2010-2013



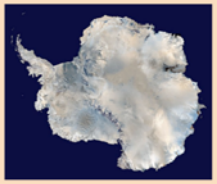
Global high resolution topography

Detection of active faults

LIST
Launch 2016-2020

Societal Challenge: **Earthquake Early Warning**

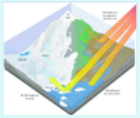
Identify active faults and predict likelihood of earthquakes to enable effective investment in structural improvements, inform land use decisions, and provide early warning of impending earthquakes



Ice sheet deformation and dynamics

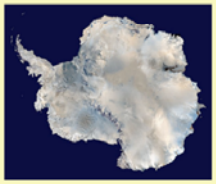
DESDynI
Launch 2010-2013

Absolute spectrally resolved IR radiance



Incident solar and spectrally resolved reflected irradiance

CLARREO
Launch 2010-2013

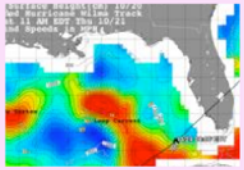


Ice sheet mass, volume, and distribution

GRACE-II
Launch 2016-2020

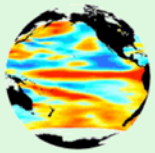
Ice sheet thickness and volume

ICESat-II
Launch 2010-2013



Sea level measurements extended into coastal zones

SWOT
Launch 2013-2016



Sea surface temperature

PATH
Launch 2016-2020

***Societal Challenge:* Sea Level Rise**

Climate predictions based on better understanding of ocean temperature and ice sheet volume changes and feedback to enable effective coastal community planning

Nutrients and water status of vegetation, soil type and health

HysplRI
Launch 2013-2016

Ocean eddies and currents

SWOT
Launch 2013-2016

CO_2 measurements: Day/night, all seasons, all latitudes

Inventory of global CO_2 sources and sinks

ASCENDS
Launch 2013-2016

Height and structure of forests

DESDynI
Launch 2010-2013

Dynamics of coastal ecosystems, river plumes, tidal fronts

GEO-CAPE
Launch 2013-2016

Soil freeze/ thaw state

Soil moisture effect on vegetation

SMAP
Launch 2010-2013

Improved estimates of coastal upwelling and nutrient availability

XOVWM
Launch 2013-2016

Organic material in surface ocean layers

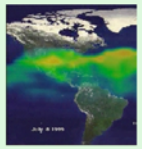
ACE
Launch 2013-2016

***Societal Challenge:* Ecosystem Services**

Improved land use, agricultural, and ocean productivity forecasts to improve planting and harvesting schedules and fisheries management

Three dimensional tropospheric wind profiles

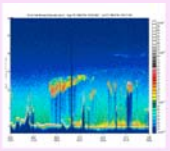
3D-Winds
Launch 2020+



Identification of human vs. natural sources for aerosols and ozone precursors

Observation of air pollution transport in North, Central, and South America

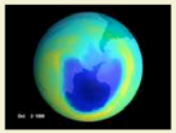
GEO-CAPE
Launch 2013-2016



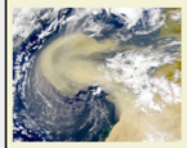
Cloud and aerosol height

Aerosol and cloud types and properties

ACE
Launch 2013-2016

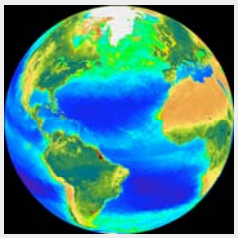


Vertical profile of ozone and key ozone precursors



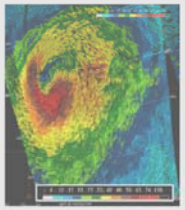
Global aerosol and air pollution transportation and processes

GACM
Launch 2016-2020



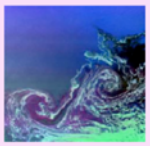
***Societal Challenge:* Air Quality**

More reliable air quality forecasts to enable effective urban pollution management.



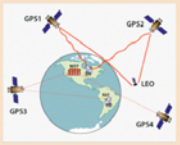
High resolution ocean vector winds

XOVWM
Launch 2013-2016



Ocean eddies and currents

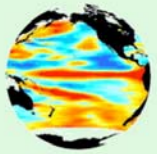
SWOT
Launch 2013-2016



Pressure/ temperature/ water vapor profiles

GPSRO
Launch 2010-2013

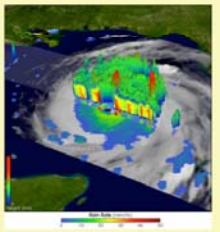
Temperature and humidity profiles



Sea surface temperature

PATH
Launch 2016-2020

Three dimensional tropospheric wind profiles



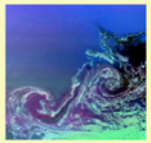
Hurricane wind fields

3D-Winds
Launch 2020+

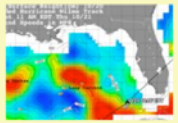
Societal Challenge: **Improved Extreme Storm Warnings**
Longer-term, more reliable storm track forecasts and intensification predictions to enable effective evacuation planning

Linkage between terrestrial water, energy, and carbon cycle

SMAP
Launch 2010-2013

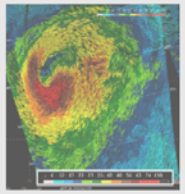


Ocean eddies and currents



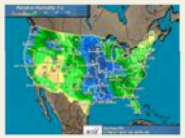
Sea level measurements extended into coastal zones

SWOT
Launch 2013-2016

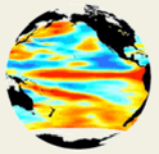


High resolution ocean vector winds

XOVWM
Launch 2013-2016

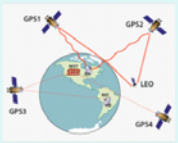


Temperature and humidity profiles



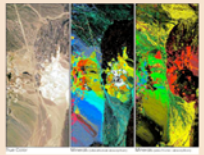
Sea surface temperature

PATH
Launch 2016-2020



Pressure/ temperature/ water vapor profiles

GPSRO
Launch 2010-2013



Spectra to identify locations of natural resources

HysplRI
Launch 2013-2016

CO_2 measurements: Day/night, all seasons, all latitudes

Inventory of global CO_2 sources and sinks

ASCENDS
Launch 2013-2016

Three dimensional tropospheric wind profiles

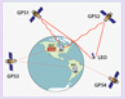
3D-Winds
Launch 2020+

***Societal Challenge:* Energy Security**

Improved energy security through more effective oil and gas exploration, safer extraction through improved marine forecasts, optimized placement of wind farms through measurement of global winds, better energy conservation through improved heating/cooling forecasts, and support of carbon trading and energy policy.

Changes in carbon storage in vegetation

DESDynI
Launch 2010-2013



Pressure/ temperature/ water vapor profiles

GPSRO
Launch 2010-2013

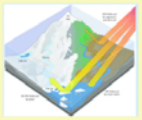
Estimate of flux of low-salinity ice out of Arctic basin

ICESat-II
Launch 2010-2013

Aerosol and cloud types and properties

ACE
Launch 2013-2016

Absolute spectrally resolved IR radiance



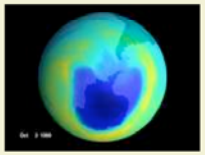
Incident solar and spectrally resolved reflected irradiance

CLARREO
Launch 2010-2013

CO_2 measurements: Day/night, all seasons, all latitudes

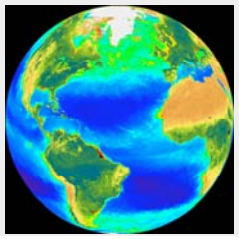
Connection between climate and CO_2 exchange

ASCENDS
Launch 2013-2016



Vertical profile of ozone and key ozone precursors

GACM
Launch 2016-2020



***Societal Challenge:* Climate Prediction**

Robust estimates of primary climate forcings for improved climate forecasts, including local predictions of the effects of climate change